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ORIGINAL RESEARCH ARTICLE

# Queen excluders enhance honey production in African honey bees, *Apis mellifera*, by limiting brood rearing during peak nectar flow

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## Summary

Unlike honey bees in temperate regions, those in tropical Africa exhibit a strong tendency towards continuous brood rearing rather than storing honey, which is a behaviour that lowers both the productivity and commercial value of African bees. In this study, the possibility of maintaining a balance in resource allocation between brood rearing and honey storage was assessed. Twelve colonies were examined, half of which were fitted with queen excluders three weeks before an expected honey harvest, while half were used as controls. Data on the honey yields and brood populations of the colonies were collected during four flowering seasons over a two-year period. The mean brood populations of all of the colonies did not differ significantly when the queen excluders were inserted into the six treatment colonies. However, at honey harvest, three weeks later, there was a highly significant difference in the mean brood population between the treatment and control groups. Colonies without queen excluders continued to rear brood, even during peak honey flow periods. The partial limiting of queen egg laying using queen excluders significantly reduced the average colony brood population compared to the control group at peak honey flow. The seasonal average honey yields were significantly different between the control and treatment groups. Under African conditions, in which bees tend to rear brood continuously even at peak honey flow and when flowering periods are short, the use of queen excluders during such periods would probably enhance honey yields of colonies.

# Spanish Abstract

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### Resumen

Unlike honey bees in temperate regions, those in tropical Africa exhibit a strong tendency towards continuous brood rearing rather than storing honey, which is a behaviour that lowers both the productivity and commercial value of African bees. In this study, the possibility of maintaining a balance in resource allocation between brood rearing and honey storage was assessed. Twelve colonies were examined, half of which were fitted with queen excluders three weeks before an expected honey harvest, while half were used as controls. Data on the honey yields and brood populations of the colonies were collected during four flowering seasons over a two-year period. The mean brood populations of all of the colonies did not differ significantly when the queen excluders were inserted into the six treatment colonies. However, at honey harvest, three weeks later, there was a highly significant difference in the mean brood population between the treatment and control groups. Colonies without queen excluders continued to rear brood, even during peak honey flow periods. The partial limiting of queen egg laying using queen excluders significantly reduced the average colony brood population compared to the control group at peak honey flow. The seasonal average honey yields were significantly different between the control and treatment groups. Under African conditions, in which bees tend to rear brood continuously even at peak honey flow and when flowering periods are short, the use of queen excluders during such periods would probably enhance honey yields of colonies.

**Keywords:** brood-rearing, honey production, queen excluder, tropical African honey bees

# Introduction

The African and temperate European races of honey bees, *Apis mellifera,* differ significantly in the extent to which they invest their basic resources. The former group of bees exhibit adaptations geared toward brood rearing and subsequent reproductive swarming; while the latter, towards massive storage of resources (Hepburn and Radloff, 1998). It has been inferred that tropical bees are continuously selected to invest more in brood rearing to compensate for losses as a result of predator and climatic pressures (Seeley, 1985). Indeed, African races of *A. mellifera* can raise 50% more broods than European bees in hives of an identical volume over the same time period (Ruttner, 1988). Conversely, the same amount of honey that can be obtained in six weeks during a favourable summer in temperate regions may require six months in tropical Africa (Douhet, 1979; 1980), which also reflects fundamental differences in the utilisation of incoming resources.

In many tropical climates, the seasonal flowering phenology of bee plants and the brood-rearing cycles of bees are biphasic (Crane, 1990; Hepburn and Radloff, 1998). Therefore, the time intervals of forage scarcity periods are shortened, which may also affect the hoarding tendency of tropical bees. Moreover, in most of the Sahel, rainfall is meagre, and subsequent flowering periods are relatively short. In such environmental conditions, beekeepers cannot expect to benefit from high honey yields if the bees tend to utilise the resources available for continuous brood rearing. Under tropical conditions, during the honey harvest, it is a common phenomenon to observe an excess of brood compared to honey production, which is completely undesirable from a beekeeping perspective. Moreover, the bees are adapted to migrate and exploit the resources available in ecologically different habitats at different times (Chandler, 1976; Castagné, 1983; Hepburn and Radloff, 1995).

Although honey production has been reported to be proportional to honey bee populations (Szabo and Lefkovitch, 1989), continuous growth of the brood population may not enhance honey production (Woyke, 1984; Winston, 1987) because colonies invest much of their resources (nectar and pollen), labour and time in brood rearing. Schneider and Blyther (1988) reported that *A. m. scutellata* commonly stores little food and devotes 78% of comb space to brood production. In this regard, Harbo (1993) estimated that 163 mg of honey is required to rear one worker bee from the egg to the pupa stage, and approximately 6.5 kg of honey is therefore required to rear 40,000 worker bees during one brood cycle.

If a colony continues to rear broods during nectar flow, a considerable amount of honey will be consumed by the brood population. The high brood-rearing tendency of tropical African honey bees has likely greatly affected their productivity in commercial terms and explains the slow expansion of commercial beekeeping using African bees, which is still dominated by small-scale household beekeeping.

To solve this problem, it is imperative that colonies have to be managed to maintain a balance in the allocation of resources for brood rearing vs. honey production. This might be achieved through partially limiting of the continuous egg-laying by queens using queen excluders during peak nectar flows and diverting workers towards nectar gathering and honey production. However, despite the introduction of queen excluders in many African countries, the general belief is that queen excluders are useful only for separating the brood and honey chambers for the purpose of maintaining honey quality. Beekeepers also believe that honey bee colonies can produce an equal amount of honey without queen excluders, and there is a general reluctance to buy and use this device. In this regard currently, there is no tangible information available on the contribution of queen excluders towards improving the honey yields of colonies under tropical African honey bee conditions. With this background in mind, the effect of using queen excluders on honey yields through the partial restriction of egg laying of a queen during peak honey flow periods was assessed.

# Materials and methods

The experiments were conducted at the Holetta Bee Research Center in Ethiopia (38.32E, 9.15N, alt. 2400 m). The experimental design was based on the flowering phenology of bee plants in the area, for which a flowering calendar has been maintained for over 25 years. Likewise, the brood-rearing cycles, honey flow and dearth periods in the region are also known. Apart from differences of a few days, the seasonal flowering and brood-rearing cycles recur more or less at the same time every year. These periods are governed by the onset and cessation of the rains. One flowering flush occurs after the minor rainy season (May-June) in the study area and a second one after the main rainy period (September-October). One dearth period occurs during the dry season (December-March), and the other during the rainy season (July-August). Thus, the experimental design was based on large, historical flowering phenology and metrological databases.

The study was conducted from 2007-2009 using 12 honey bee colonies (*Apis mellifera* L) in Zander movable-frame box hives with supers each. The colonies for this experiment were selected from the research centre's apiary and were more or less equally populous. At the beginning of the experiment, each selected colony had an average of two combs of stored pollen, three combs of nectar and honey, about five brood combs, and the adult bees covered all 20 frames in the base and super. The colonies were randomly assigned to the treatment ($n = 6$) and control ($n = 6$) groups.

The brood-rearing status of the colonies was continually checked before determining when the queen excluders should be inserted in the six treatment colonies. In the study area during the September to October flowering season, honey flow usually begins around the first week of October and extends to the end of October. In the May to June flowering season, honey flow begins around the first week of June and ceases at the end of June. A queen excluder (5 mm mesh) was inserted into each of the treatment colonies at the beginning of each honey flow, three weeks before the expected honey harvest, while the control colonies were without queen excluders. All of the colonies were maintained in the same apiary with equal access to the surrounding natural bee forage. Routine dearth and active period management activities, such as reducing and adding honey supers, maintenance feeding during dearth periods and controlling reproductive swarming through queen cell removal, were applied to all colonies.

The brood populations were quantified twice during each honey flow season in both the treatment and control groups using frames with a wire grid to form equal unit areas (25 $cm^2$). The first measurements were made just prior to the insertion of the queen excluders, and the second measurements were performed three weeks later at honey harvest. The brood population measurements and honey yield records were taken during the flowering seasons (two per year) for two years.

### Statistical analysis

Three-way ANOVA analyses were used to test for differences in brood population sizes before and after the insertion of queen excluders, between harvesting seasons and between the treatment and control groups. Differences in the mean honey yields between the treatment and control groups and harvesting seasons were determined using two-way ANOVA analyses. Tukey's multiple pairwise comparison tests were employed to test for significant group effects. Levene's test and the Kolmogorov-Smirnov test were used to check for homogeneity of the variances and normality, respectively. Correlation analyses were performed to determine whether there was a relationship between the brood populations and honey yields of the colonies. The mean values and standard deviations (S.D.) of the variables were recorded. The data were analysed using Statistica 9.0 (StatSoft, 2009).

## Results

In this experiment, the honey flow started as expected, following the trend of data collected from previous years. The onset of the dearth periods were abrupt, both at the end of June, with the beginning of heavy rains, and at the end of November, in the dry season. The mean sizes of the brood populations of the colonies for both seasons before the queen excluders were inserted in the hives were 33.43 ± 6.57 x $10^3$ and 32.40 ± 4.06 x $10^3$ for the treatment and control groups, respectively, and the variations in the brood size were not significantly different (Tukey: $n = 24$, $P = 0.8394$, Table 1 & Fig. 1). However, the mean brood populations of the colonies at honey harvest (three weeks after the queen excluders had been inserted in the hives) were 10.06 ± 1.98 x $10^3$ and 26.51 ± 3.27 x $10^3$ for the treatment and control groups, respectively (Table 1 & Fig. 1), which were highly significantly different (Tukey: $n = 24$, $P < 0.0001$). The average honey yield per harvest for all of the colonies in the treatment group for both seasons (12.51 ± 3.82 kg/hive) was significantly higher than that of the control group (9.44 ± 3.46 kg/hive) (Table 1 & Fig. 2). The ANOVA results showed that the amount of honey obtained from the colonies with a queen excluder was significantly greater than was collected from those without queen excluder ($n = 24$, $P = 0.0026$, Table 1). The response variables, brood population size and honey yield, both passed tests of normality (brood size: K-S $d = 0.0726$, $P > 0.20$; honey yield: K-S $d = 0.1083$, $P > 0.20$). Levene's test showed no evidence of heterogeneity of the variances in brood size ($F_{7,88} = 1.63$, $P = 0.1393$) nor in honey yield ($F_{3,44} = 0.00004$, $P = 0.9999$).

When we consider seasonal variations, on insertion of the queen excluders (day 1), in the September-October season, mean colony brood populations of 29.89 ± 5.95 x $10^3$ and 30.59 ± 2.74 x $10^3$ were recorded for the treatment and control groups, respectively, and these values were not significantly different (Tukey: $n = 12$, $P = 0.9998$; Table 1). However, at the honey harvest, 21 days later, the mean brood populations were 9.38 ± 1.83 x $10^3$ and 25.90 ± 3.06 x $10^3$ for the treatment and control groups, respectively, which were significantly different (Tukey: $n = 12$, $P < 0.0001$; Table 1). For the September-October harvest, average honey yields of 10.95 ± 2.5 kg/colony and 7.81 ± 1.84 kg/colony were obtained for the treatment and control groups, respectively, and these results were significantly different ($n = 12$, $P = 0.0336$; Table 1).

Similarly, in the May-June harvest season, the mean colony brood populations upon insertion of the queen excluders were 36.98 ± 5.24 x $10^3$ and 34.21 ± 4.45 x $10^3$ for the treatment and control groups, respectively, and the variations in brood sizes between the groups were not significantly different (Tukey: $n = 12$, $P = 0.6484$; Table 1).

***Table 1.*** The mean ± S.D. of the brood population sizes and honey yields of the colonies in the treatment and control groups in different honey harvesting seasons. Day 1 = during queen excluder inserted; day 21 = after 21 days of queen excluder inserted. Tukey: Different letters in same row indicate a significant difference

| Harvesting Season | Variable | Treatment | Control | *P* value |
|---|---|---|---|---|
| Sept - Oct | Brood population x $10^3$ (day 1) | 29.89 ± 5.95$^a$ | 30.59 ± 2.74$^a$ | 0.9998 |
| | Brood population x $10^3$ (day 21) | 9.38 ± 1.83$^a$ | 25.90 ± 3.06$^b$ | < 0.0001 |
| | Honey yield in kg (day 21) | 10.95 ± 2.50$^a$ | 7.81 ± 1.84$^b$ | 0.0336 |
| May - June | Brood population x $10^3$ (day 1) | 36.98 ± 5.24$^a$ | 34.21 ± 4.45$^a$ | 0.6484 |
| | Brood population x $10^3$ (day 21) | 10.73 ± 1.96$^a$ | 27.12 ± 3.49$^b$ | < 0.0001 |
| | Honey yield in kg (day 21) | 14.08 ± 4.36$^a$ | 11.07 ± 3.99$^b$ | 0.0414 |
| Both Seasons' Data | Brood population x $10^3$ (day 1) | 33.43 ± 6.57$^a$ | 32.40 ± 4.06$^a$ | 0.8394 |
| | Brood population x $10^3$ (day 21) | 10.06 ± 1.98$^a$ | 26.51 ± 3.27$^b$ | < 0.0001 |
| | Honey yield in kg (day 21) | 12.51 ± 3.82$^a$ | 9.44 ± 3.46$^b$ | 0.0026 |

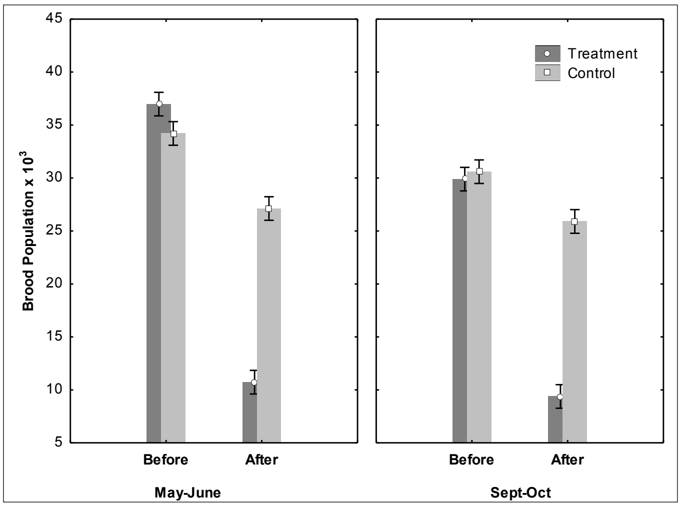


***Fig. 1.*** Brood populations (mean ± S.E.) of the colonies before and after the insertion of queen excluders and by harvesting season.

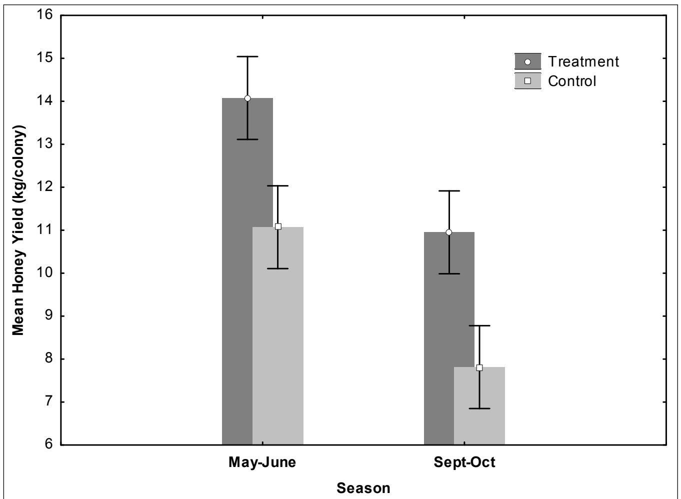


***Fig. 2.*** Honey yields (mean ± S.E.) of the colonies by treatment and harvesting season.

However, at honey harvest, the values were 10.73 ± 1.96 x $10^3$ and 27.12 ± 3.49 x $10^3$ for the treatment and control groups, respectively, which were significantly different ($n$ = 12, $P$ < 0.0001). The honey yields obtained in the May-June harvest were 14.08 ± 4.36 kg/colony and 11.07 ± 3.99 kg/colony for the treatment and control groups, respectively, which were again significantly different ($n$ = 12, $P$ = 0.0414; Table 1). The mean honey yields recorded in the May-June harvest season were significantly greater than yields in the September-October season for both the treatment and control groups ($n$ = 24, $P$ = 0.0018, Fig. 2).

Generally, the data on the brood populations and the honey yields of the colonies showed a strong positive correlation ($r$ = 0.727, $n$ = 48, $P$ < 0.0001) prior to the insertion of queen excluders (before honey flow); however, the correlation between the brood population and the honey yield was negatively correlated at honey harvest ($r$ = - 0.187).

# Discussion

The average amount of honey obtained from the control group colonies was significantly lower than from colonies with queen excluders (Table 1). The results of this study indicate that tropical African honey bees indeed exhibit a strong tendency to continue brood rearing, even towards the end of a honey flow period, which is behaviour that has significant adverse effects on the honey yield of the colonies. Similarly, Schneider and Blyther (1988) reported that *A. m. scutellata* commonly stores little food and devotes much of its comb space to the brood production.

The existence of a positive correlation between the brood populations and honey yields of the colonies prior to the insertion of queen excluders may indicate that early, large brood colony populations contribute to the subsequent productivity of the colony. The negative and weak correlation detected between the brood population and honey yield at honey harvest indicates that the existence of a large brood population at peak honey flow has no positive effect on the honey yields of the colonies. This result is consistent with the findings of Szabo and Lefkovitch (1989), who reported an absence of a significant correlation between honey production and brood populations reared late during a peak honey flow period. Moreover, Nolan (1925) stated that the quantity of nectar gathered by a colony depends not only on the total number of bees in the colony during a honey flow but also on the relative number of nectar foragers.

Minimising the brood population during a peak honey flow period through partial limiting of egg laying by queens using queen excluders significantly decreased the size of the brood population. This contributed to the higher production of honey in the treatment group (Table 1), which was approximately 25% greater than in the control group on average. This effect may occur because brood rearing consumes much of the workers' labour, as demonstrated by the observation of 1,300 nurse bees visiting a single larva per day (Lindauer, 1953), and because larvae consume honey at a rate of 163 mg honey/larval stage (Harbo, 1993). Based on this estimation, if 16,000 broods are minimised for just one brood cycle per colony during the peak honey flow period using a queen excluder, it is possible to save more than 2.6 kg of honey per colony/harvest from larval consumption alone.

The flowering patterns of honey bee plants in the study area are biphasic (showing two peak flowering periods). Moreover, there are other plants that bloom outside of these peak flowering periods that provide an alternate food source during feed shortage gaps. As a result, the critical dearth period in the area is either short or totally absent. This may have encouraged the continuous brood-rearing tendency of the bees, as opposed to storing large reserves, which is the survival strategy observed in bees in temperate regions. The absence of an inclination to store large quantities of honey reflects the unique survival strategy of tropical African honey bees, which involves migration to neighbouring areas where alternative forage resource is available (Crane, 1990).

This study further showed that during an extended, good honey flow period, such as those that occurred in the area during the May-June flowering periods, the colonies produced comparable amounts of honey, even without queen excluders. Therefore, the use of a queen excluder is more important during short flowering periods and poor flow conditions (September-October) (Table 1). Most of the honey bee plants in the study area that flower between September and October are annual herbs with a short flowering period. Flowering ceases abruptly, usually before colonies reach their optimum peak population levels and before they can store sufficient nectar. In contrast, during the May-June period, even though fewer species of honey bee plants are flowering, there is a dense population of trees with an extended flowering period, which enables the colonies to attain their peak population size and to produce more honey.

Based on the findings of this study, it is evident that the use of queen excluders may improve the honey yields of colonies that show strong and continuous brood-rearing tendencies, and this indicate that the amount of honey that can be saved from larval consumption due to reducing brood-rearing activities during peak honey flow periods is significant. Therefore, the partial limiting of queen's egg laying using queen excluders for short periods (during peak honey flow) would improve the honey yields of honey bee colonies by maintaining a balance in resource allocation between brood rearing and honey storage. However, if the queen excluder is inserted before the colonies have attained a sufficient work force, it may affect the honey yield; similarly, if the insertion is delayed to near the end of the honey flow, it is unlikely to contribute the honey yield of the colony. Careful determination of the appropriate timing for inserting queen excluders, based on the brood populations and the flowering patterns in a given area, is of paramount importance.

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